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Research Paper

Effect of Fibre Hybridization on Compressive Strength, Split Tensile Strength and Water Permeability of SFRC

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ABSTRACT

The paper presents results of an investigation conducted to study the compressive strength, split tensile strength and water permeability of fibre concrete mixes containing steel fibres in mono, binary and ternary combinations. Steel fibres of different lengths i.e. 12.5 mm, 25 mm and 50 mm having constant diameter of 0.6 mm were used to obtain mono, binary and ternary combinations. A reference concrete mix with no fibres was also used for comparison purpose. The total fibre volume fraction was kept at 1.0% in all the mixes. Compressive strength, split tensile strength and water permeability tests were conducted of specimens of size 100 x 100 x 100 mm after 28 days of curing. It has been observed that a fibre combination of 33% 12.5 mm + 33% 25 mm + 33% 50 mm long fibres can be adjudged as the most appropriate combination to be employed in HySFRC for compressive strength, split tensile strength and water permeability.

1 Introduction

Concrete is one of most widely used construction material in the world. Its properties like easy mould ability into any desired shape, easy availability of its constituent materials, cost effectiveness, and many other advantages make it popular construction material. Those materials demand with improved properties like strength, stiffness, toughness, ductility and last, but not the least, durability. Durability is the basic requirement of any concrete structure as it should be able to withstand all stresses and remain functional throughout its designed life span. Some of the reasons for failure of structures are poor design, use of poor quality materials, bad workmanship, deterioration of concrete due to ingress of harmful ingredients etc. Incredibly vast research work has been carried out to study the effect of different factors such as cement content, type and size of aggregates, curing conditions, different materials like silica fume, fly ash and mono fibres on the permeability of concrete [1-15]. From the past few decades, Fibre Reinforced Concrete (FRC) has popularized as addition of short, discrete fibres enhances the mechanical properties of the resulting matrix. The fibres in concrete serve as crack arresters, thus delaying the appearance of cracks and creating a stage of slow crack propagation. The ductility of the

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composite is increased compared to the unreinforced matrix with a corresponding increase in tensile strength. The use of continuous aligned fibres in a cement matrix is fundamentally not different from conventional reinforced concrete, or pre-stressed concrete, where the large diameter reinforcing bars or the small diameter pre-stressing wires behave like continuous aligned fibres in a cement matrix. The phenomenon of multiple cracking and of composite action in such materials is well known and well established for over a century. Considerable research, development, and applications of FRC are taking place throughout the world. Industry interest and potential business opportunities are evidenced by continued new developments in fibre reinforced construction materials. These new developments are reported in numerous research papers, international symposia, and state of the art reports issued by various professional societies. Many researchers reported that the addition of mono discrete steel fibres in FRC enhances its compressive strength citing the reason that short fibres reduce the micro cracking in concrete [16-21].

Steel Fibre Reinforced Concrete (SFRC) is a well established construction material these days. The investigations carried out by many of the researchers [18-24] have shown that the structural properties like compressive, tensile and flexural strength etc. undergo a significant enhancement with the addition of short discrete randomly distributed fibres in the plain concrete.

Recently, considerable interest has developed in Hybrid Fibre Reinforced Concrete (HyFRC). For optimal behaviour, different types of fibres have been combined. The benefits of fibre hybridization to achieve superior tensile strength and flexural toughness were recognized. After a long period of relative inactivity, there appears to be renewed interest in HyFRC and efforts are underway to develop the science and rationale behind fibre hybridization. However, there is scarcity of data available on the water permeability of Hybrid Steel Fibre Reinforced Concrete (HySFRC). This investigation was, therefore, undertaken with the aim to study the effect of aspect ratio of steel fibres on binary and ternary mix hybridization of steel fibres for compressive strength, split tensile strength and water permeability of HySFRC.

2 Experimental Procedure

The basic concrete mix proportions used in this investigation for casting of the test specimens is shown in Table 1. Pozzolanic Portland Cement crushed stone coarse aggregates having maximum size of 12 mm and locally available river sand were used. The materials conformed to the relevant Indian Standard specifications. Corrugated steel fibres 12.5 mm, 25 mm and 50 mm long, with constant diameter of 0.6 mm were used in different combinations as shown in Table 2. The total fibre volume fraction was kept at 1.0%. In all, there were 8 concrete mixes containing different combinations of steel fibres. The specimen used for compressive strength, split tensile strength and water permeability tests were cubes of 100 x 100 x 100 mm size. For each mix, 9 cubes for compressive strength, split tensile strength and water permeability were cast. The compressive strength, split tensile strength and water permeability tests were conducted after 28 days of curing. In all, 72 cube specimens were tested for compressive strength, split tensile strength and water permeability in this investigation. The compressive strength tests and split tensile strength were conducted in a 2000 KN Universal Testing Machine, whereas, the water permeability tests were conducted in a Water Permeability Tester as per procedure laid down in IS: 3085-1965 [25]. The coefficient of permeability was calculated by using the Darcy's formula given below:

$$k = Q \times L / (A \times H)$$

Where k is coefficient of permeability in m/s, Q is rate of discharge in cumecs, L is dimension of the specimen measured in the direction of flow, A is area of cross section of the specimen and H is the water head causing flow measured in meters.

Table 1- Concrete Mix Proportions

Water/Cement Ratio	Sand/Cement Ratio	Coarse Aggregate/Cement Ratio
0.46	1.52	1.88

Table 2- Fibre Concrete Mixes

Mix ID	Fibre Mix Proportions by weight (%)		
	12.5* mm Long Fibres	25* mm Long Fibres	50* mm Long Fibres
Plain (No Fibres)		0	
100% 12.5 mm L [#]	100	0	0
50% 12.5 mm L + 50% 25 mm L	50	50	0
100% 25 mm L	0	100	0
50% 12.5 mm L + 50% 50 mm L	50	0	50
100% 50 mm L	0	0	100
50% 25 mm L + 50% 50 mm L	0	50	50
33% 12.5 mm L + 33% 25 mm L + 33% 50 mm L	33	33	33

* Diameter of Steel Fibres = 0.6 mm. ([#] L: Long fibres)

3 Results and Discussion

3.1 Compressive strength tests results

The results of the compressive strength tests conducted on various mixes containing steel fibres in mono, binary and ternary combinations as shown in Table-2 having 1.0% fibre volume fraction and cured for 28 days, are presented in Fig.-1. The compressive strength of reference concrete mix made without fibres is also presented in Fig.-1 for comparison. It can be generally observed from Fig.-1 that maximum increase in the compressive strength of the order of 26.61% was observed in a mix containing 100% 25 mm long fibres.

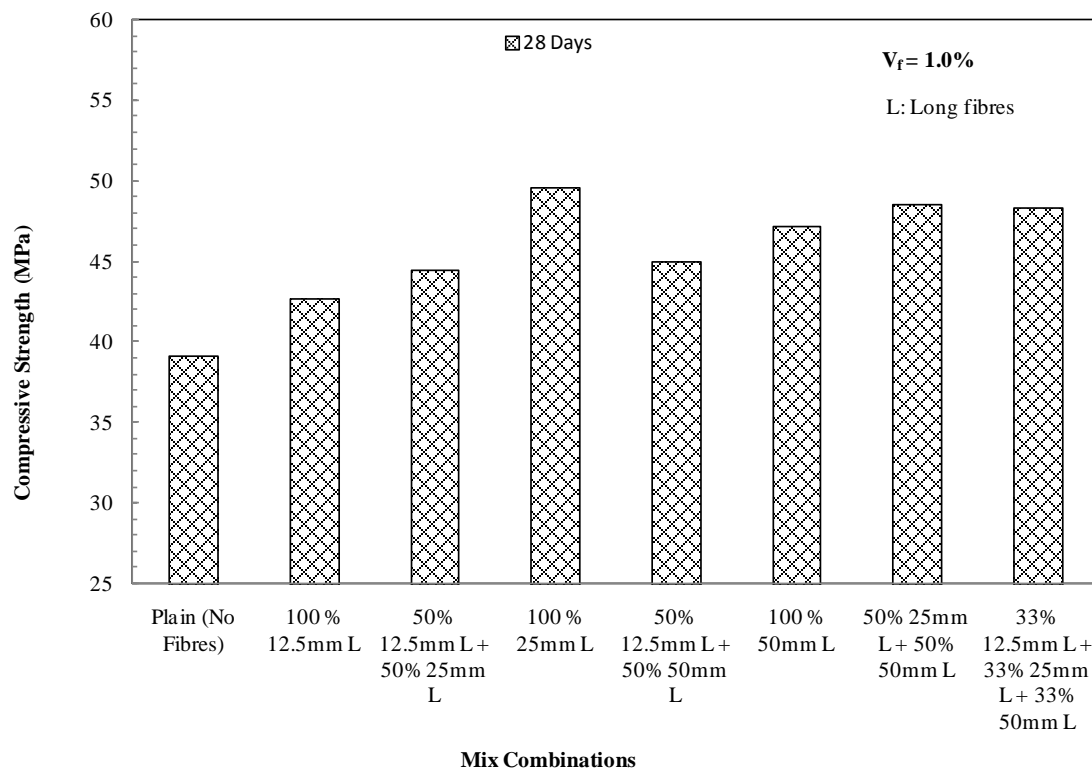


Fig. 1 Compressive strength results for mono, binary and ternary HySFRC mixes (12.5mm, 25mm and 50mm long steel fibres).

For mixes containing mono steel fibre, with the addition of 100% 12.5 mm long fibres, the compressive strength has been observed to be increased by 8.85% with reference to plain concrete. Similarly, with the addition of 100% 25 mm long

fibres, the compressive strength was increased by 26.61% whereas, with the addition of 100% 50 mm long fibres, an increase in the compressive strength of the order of 20.32% was observed.

For HySFRC mix containing binary combination of steel fibre, with the addition of 50% 12.5 mm + 50% 25 mm long steel fibres, an increase in the compressive strength of the order of 13.51% over plain concrete mix was observed. For HySFRC mix which contained 50% 12.5 mm + 50% 50 mm long steel fibres, the compressive strength was increased by 14.89% over plain concrete mix. Similar trends were observed for mix 50% 25 mm + 50% 50 mm, and the increase in compressive strength of HySFRC mix over plain concrete mix was observed to be 23.88%.

However, for HySFRC mix containing ternary combinations of steel fibres such as 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres, the increase in the compressive strength over plain concrete was observed to be 23.37%. It is observed that the highest compressive strength at 28 days of curing was given by a mix containing 100% 25 mm long fibres which is followed by a mix containing 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres.

3.2 Split tensile strength tests results

The results of the split tensile strength tests conducted on various mixes containing steel fibres in mono, binary and ternary combinations as shown in Table-2 having 1.0% fibre volume fraction and cured for 28 days, are presented in Fig.-2. The split tensile strength of reference concrete mix made without fibres is also presented in Fig.-2 for comparison. It can be generally observed from Fig.-2 that maximum increase in the split tensile strength of the order of 46.07% was observed in a mix containing 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres.

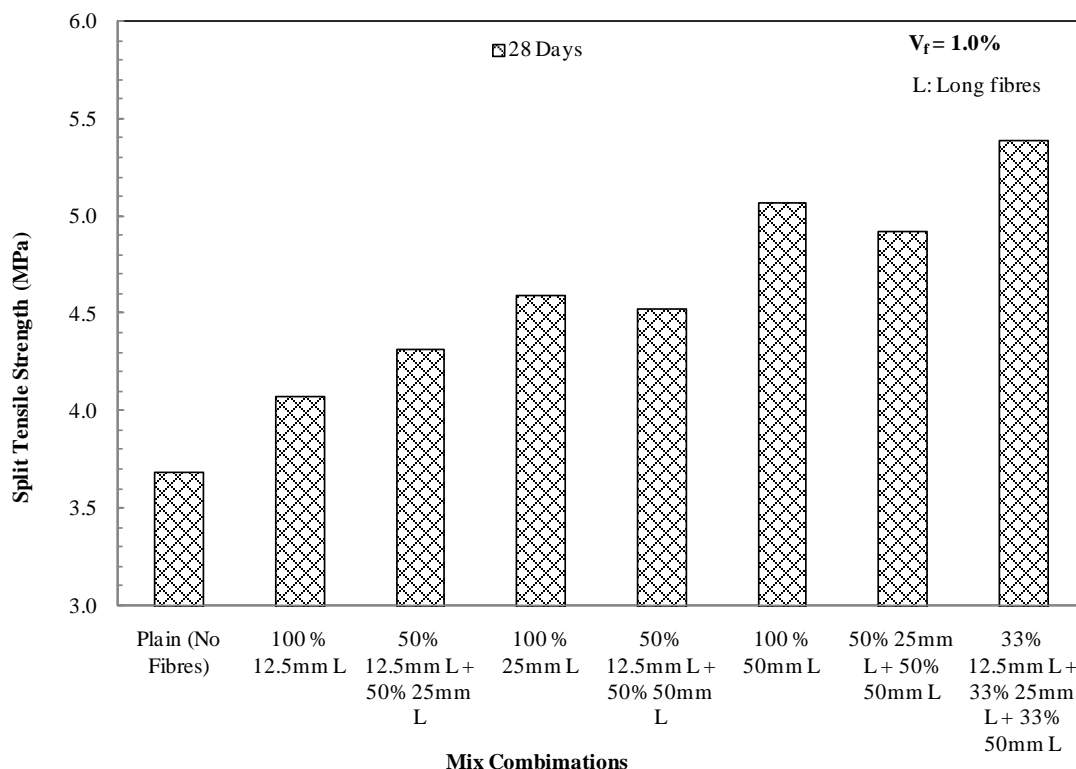


Fig. 2 Split tensile strength results for mono, binary and ternary HySFRC mixes (12.5mm, 25mm and 50mm long steel fibres).

For mixes containing mono steel fibre, with the addition of 100% 12.5 mm long fibres, the split tensile strength has been observed to be increased by 10.57% with reference to plain concrete. Similarly, with the addition of 100% 25 mm long fibres, the split tensile strength was increased by 24.66% whereas, with the addition of 100% 50 mm long fibres, an increase in the split tensile strength of the order of 37.40% was observed.

For HySFRC mix containing binary combination of steel fibre, with the addition of 50% 12.5 mm + 50% 25 mm long steel fibres, an increase in the split tensile strength of the order of 17.07% over plain concrete mix was observed. For HySFRC mix which contained 50% 12.5 mm + 50% 50 mm long steel fibres, the split tensile strength was increased by 22.76% over plain concrete mix. Similar trends were observed for mix 50% 25 mm + 50% 50 mm, and the increase in split tensile strength of HySFRC mix over plain concrete mix was observed to be 33.60%.

However, for HySFRC mix containing ternary combinations of steel fibres such as 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres, the increase in the split tensile strength over plain concrete was observed to be 46.07%. It is observed that the highest split tensile strength at 28 days of curing was given by a mix containing 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres followed by 100% 50 mm steel fibres.

3.3 Water permeability tests results

The results of the water permeability tests conducted on different fibre concrete mixes containing mono, binary and ternary combinations of steel fibres are presented in Fig.-3. The water permeability of plain concrete mix containing no fibres is also presented in Fig.-3 for reference. A significant reduction in the water permeability was observed with the addition of steel fibres to plain concrete. A maximum decrease in the water permeability of the order of 79.21% was observed for a mix containing 100% 12.5 mm long fibres.

For mono steel fibre mixes, with the addition of 100% 12.5 mm long fibres, the coefficient of water permeability was found to decrease by 79.21% over plain concrete mix. Similarly, for a mix containing 100% 25 mm long fibres, the coefficient of water permeability was found to decrease by 65.23% over plain concrete mix. For a mix made of 100% 50 mm long fibres mix, decrease in the coefficient of water permeability of the order of 51.94% was observed over plain concrete.

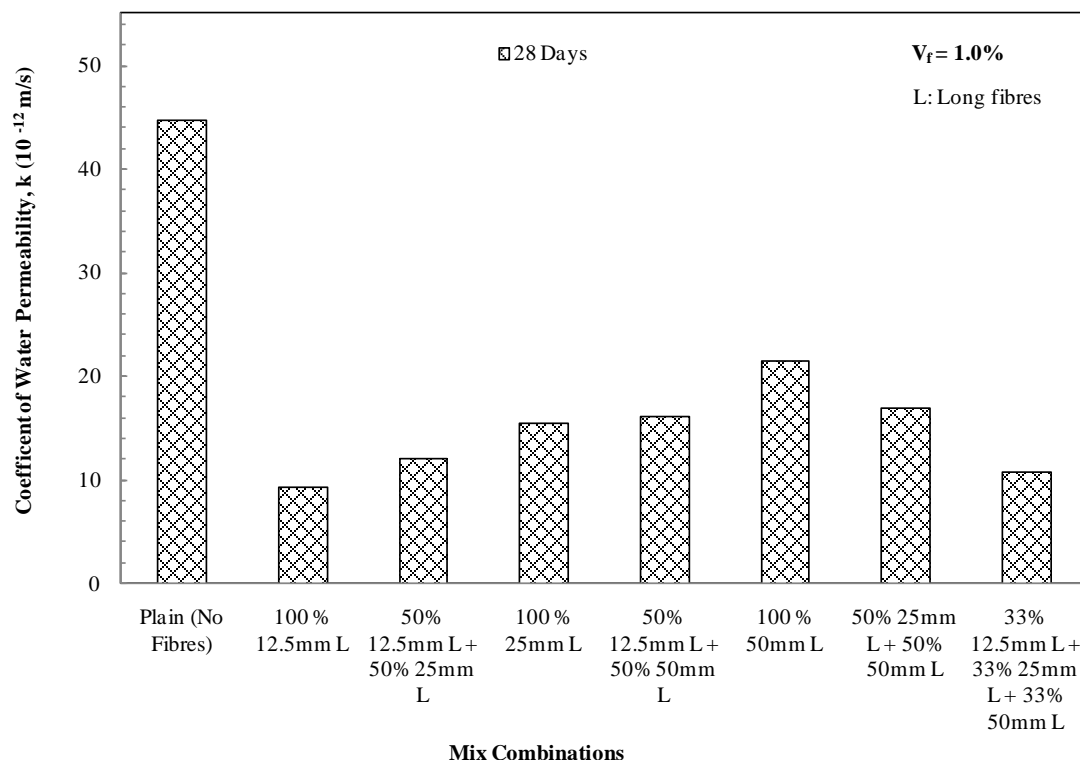


Fig. 3 Water permeability for mono, binary and ternary HySFRC mixes (12.5mm, 25mm and 50mm long steel fibres).

Similarly, for HySFRC mixes containing binary combinations of steel fibre, with the addition of 50% 12.5 mm + 50% 25 mm long steel fibres, decrease in the coefficient of water permeability of the order of 73.08% over plain concrete mix was observed. For HySFRC mix which contained 50% 12.5 mm + 50% 50 mm long steel fibres, the coefficient of water permeability was decreased by 63.98% over plain concrete mix. Similar trends were observed for a mix containing 50% 25 mm + 50% 50 mm and the decrease in the coefficient of water permeability over plain concrete mix was 61.89%.

Further, for a mix containing ternary combination of steel fibres such as 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres, the coefficient of water permeability over plain concrete was observed to be 75.74%. It is observed that the lowest coefficient of water permeability at 28 days of curing was given by a mix containing 100% 12.5 mm long fibres followed by a mix containing 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres.

It can be seen from the results of compressive strength, split tensile strength and water permeability tests presented in the preceding sections that no single fibre combination can be adjudged as the best combination for all these properties. However, it will be in the fitness of things to examine the results in more detail and to arrive at an acceptable fibre combination for all the tests conducted. It can be easily observed that the best performance in terms of split tensile strength is given by a mix containing 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres. The best fibre combination for water permeability is 100% 12.5 mm long fibres, whereas the mix made with 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres gives the second best performance in terms of water permeability. Similarly, the mix containing 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres gives the second best performance in terms of compressive strength also. Hence, it can be concluded without much loss of accuracy that for compressive strength, split tensile strength and water permeability, a fibre combination of 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres can be adjudged as the best combination.

4 Water Permeability, Compressive Strength and Split Tensile Strength

The results reported in this paper are part of a larger investigation in which a number of fibre combinations were tested at 7, 28, 90 and 120 days of curing. Only a limited results related to some selected fibre combinations and curing period of 28 days are reported in this paper. However, to relate the water permeability with the compressive strength and split tensile strength, the results of all the curing periods i.e. 7, 28, 90 and 120 days are included in Figs 4 and 5. The relation between water permeability and compressive strength for different fibre mix combinations tested in this investigation is presented in Fig. 4. It can be observed that with the increase in the compressive strength, a decrease in the water permeability of different mixes is observed. Similarly, the relationship between water permeability and split tensile strength for different fibre mix combinations tested is presented in Fig. 5. It can be observed that with the increase in the split tensile, a decrease in the water permeability of different mixes is observed.

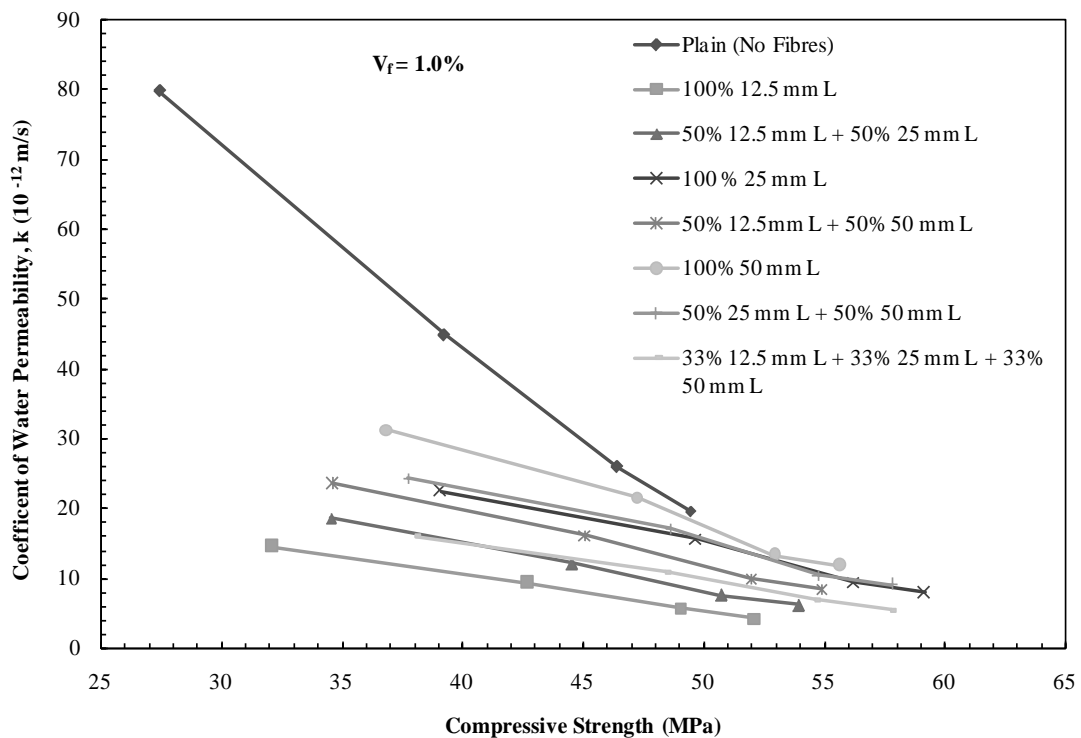


Fig. 4 Water permeability Vs compressive strength of mono, binary and ternary mixes.

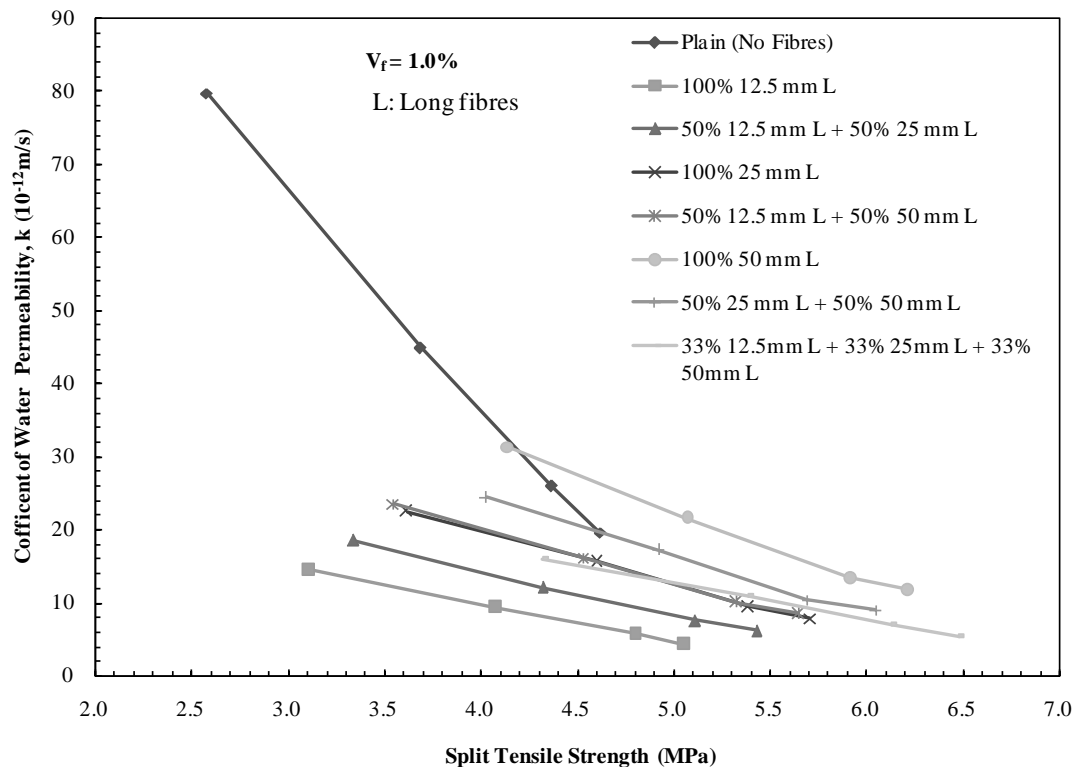


Fig. 5 Water permeability Vs split tensile strength of mono, binary and ternary mixes.

5 Conclusion

Properties of HySFRC containing different combinations of steel fibres of different lengths and plain concrete in hardened state have been investigated. Tests such as compressive strength, split tensile strength and water permeability were conducted on hardened concrete after 28 days of curing. For compressive strength, maximum increase of the order of 26.61% over plain concrete was observed in case of mix containing 100% 25 mm long steel fibres. Similarly, 46.07% increase in split tensile strength of HySFRC was observed with respect to plain concrete with a fibre mix ratio of 33% 12.5 mm + 33% 25 mm + 33% 50 mm long fibres. In case of water permeability, a maximum decrease in coefficient of water permeability of the order of 79.21% for a mix with 100% 12.5 mm long steel fibres was observed followed by a mix made of 33% 12.5 mm + 33% 25 mm + 33% 50 mm long fibres. A careful examination of the results indicates that a fibre combination of 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres can be taken as the most appropriate combination for compressive strength, split tensile strength and water permeability of HySFRC.

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